ECE 322L
Electronics 2

02/11/20 - Lecture 7

Common Drain and Common Gate Amplifiers

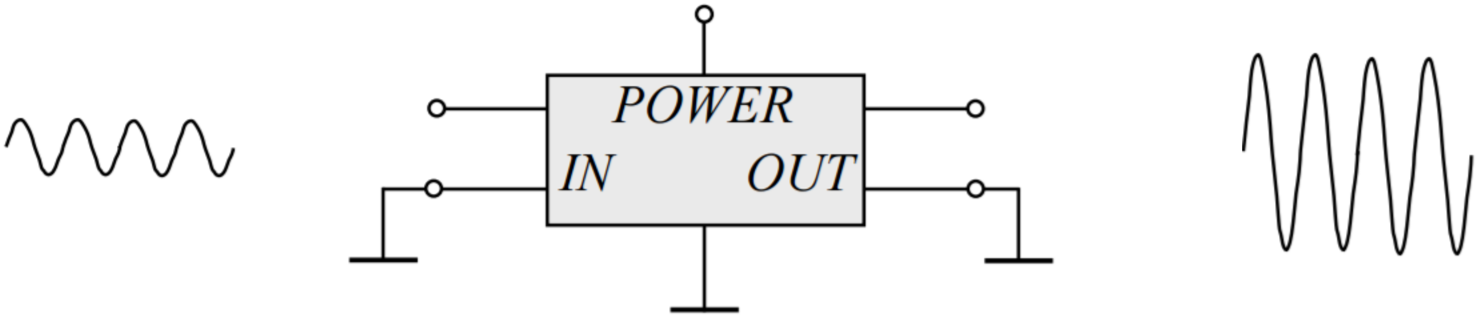
Updates and Overview

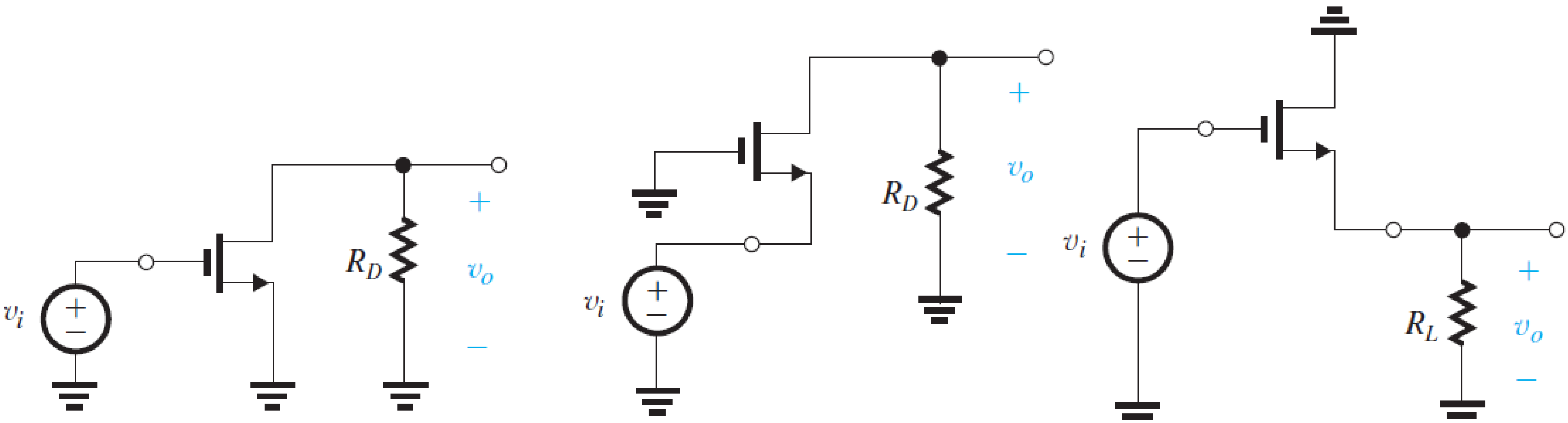
- Midterm 1 next week, Feb 18th, 11:00 am-12:15 pm.
- Practice problems in view of the midterm 1:
  - Neamen: design example 4.4 and exercise problem 4.4.

Today:

- Review of the common source (CS) amplifier
- Common Gate (CG) FET amplifiers (Neamen 4.5, S&S 5.6.5).
- Common Drain (CD) FET amplifiers (Neamen 4.4, S&S 5.6.6).

Basic configurations for FET amplifiers



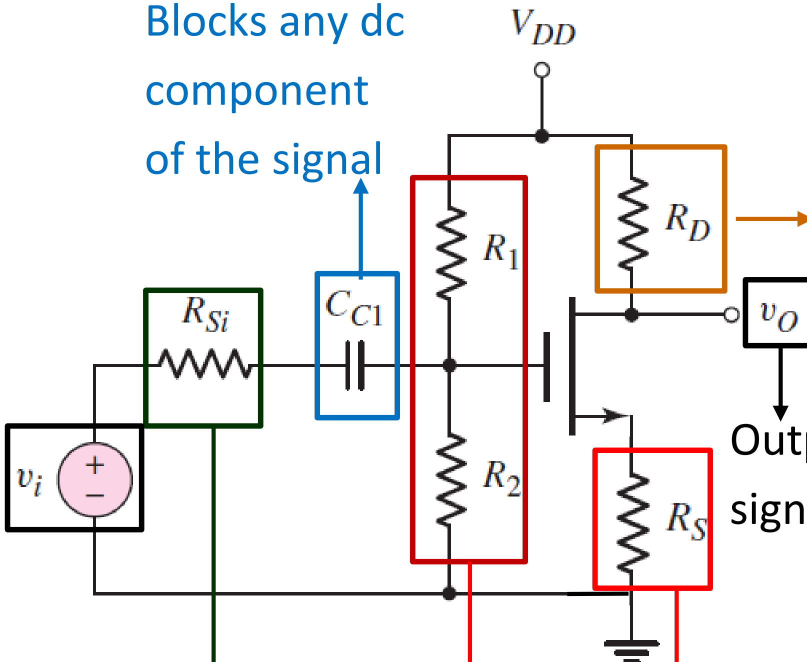


(a) Common Source (CS) (b) Common Gate (CG) (c) Common Drain (CD)

There are three basic configurations for connecting the MOSFET as an amplifier. Each of these configurations is obtained by connecting one of the three MOSFET terminals to ground, thus creating a two-port network with the grounded terminal being *common* to the input and output ports.

Common Source (CS) Amplifier w/ R_s

Blocks any dc component of the signal



R_D determines the Q point and acts as an internal load in ac.

Note: The load can also be the input resistance of the next amplification stage in a multi-stage amplifier.

Input signal

Output signal

Determine transistor bias along with V_{DD} and R_D

Internal resistance of a signal source or Thevenin equivalent of the output circuit of another amplifier stage.

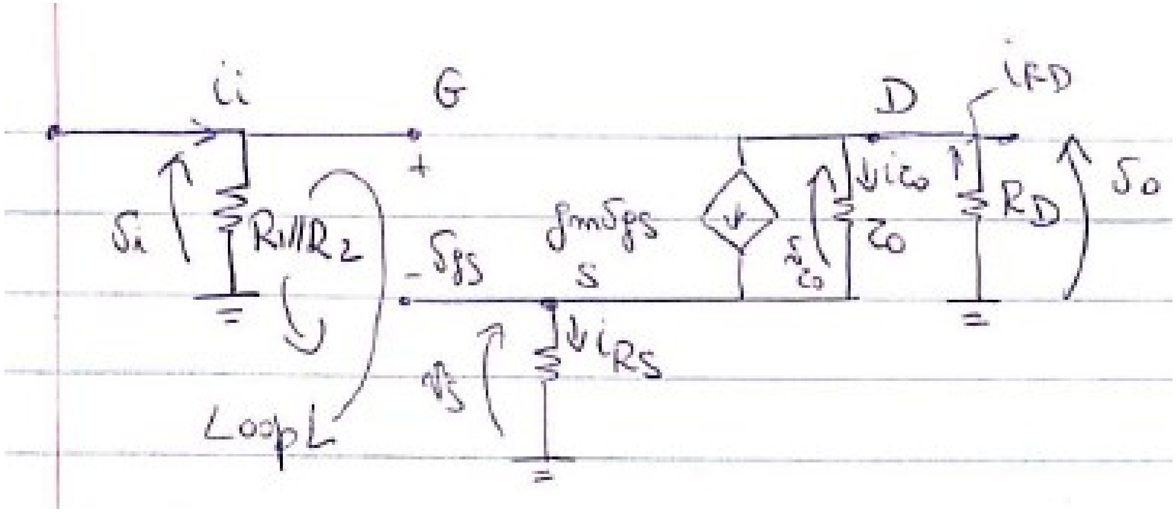
C_{c1} is typically of the order of ~10s μF. This value guarantees a much smaller capacitor impedance than R_{si} for signal with frequencies higher than 2 kHz.

$$|Z_C| = \frac{1}{2\pi f C_C} = \frac{1}{2\pi(2\times 10^3)(10\times 10^{-6})} \cong 8\,\Omega$$

C_{c1} can then be replace with a short-circuit in ac analysis of high frequency signals

Common Source (CS) Amplifier w/ R_s

Input resistance and amplifier gain



$$R_{in} = \frac{v_i}{i_i} = R_1 \parallel R_2$$

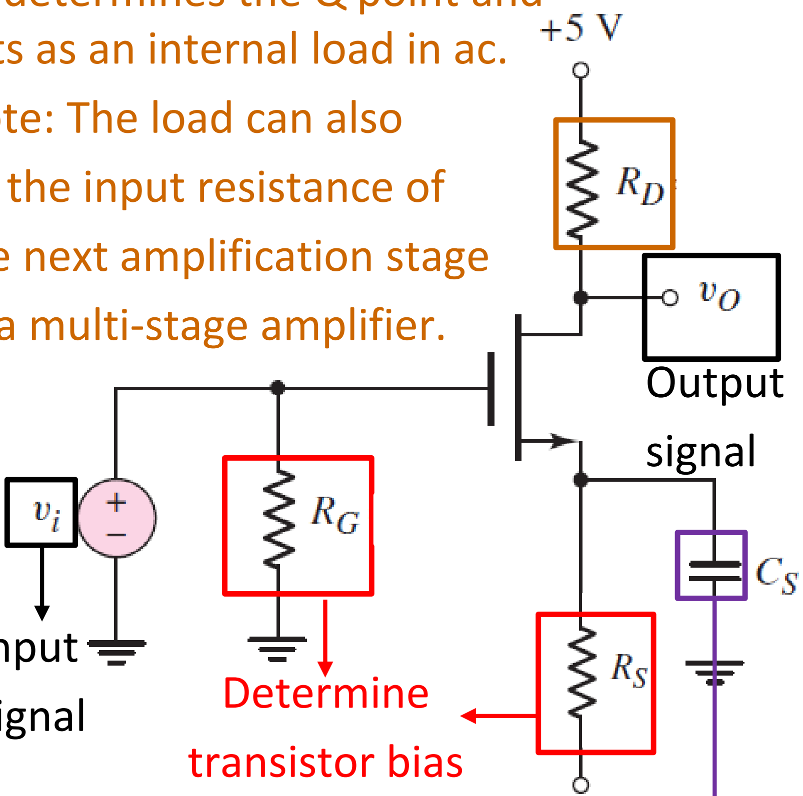
$$A_{vo} = \frac{v_o}{v_i} = -\frac{g_m R_D}{1 + g_m R_s + \frac{1}{r_o}(R_s + R_D)} \approx -\frac{g_m R_D}{1 + g_m R_s}$$

$$R_o = R_D \parallel [r_o + (1 + g_m r_o) R_s] \approx R_D \qquad r_o \gg R_s + R_D$$

Common Source (CS) Amplifier w/ Bypass Capacitor

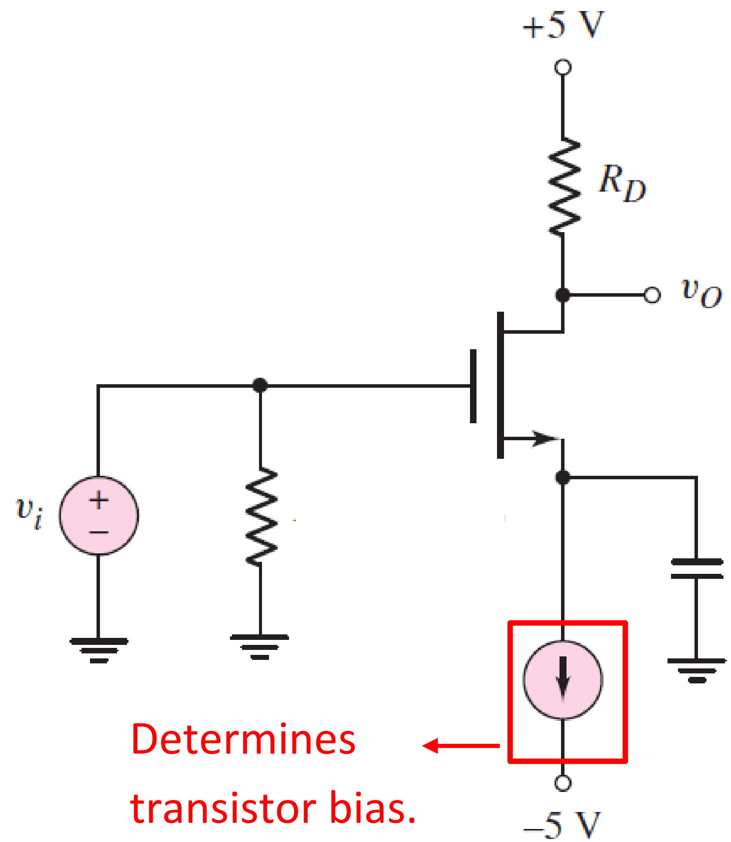
R_D determines the Q point and acts as an internal load in ac.

Note: The load can also be the input resistance of the next amplification stage In a multi-stage amplifier.



Determine transistor bias along with R_D V_{DD} and V_{SS}

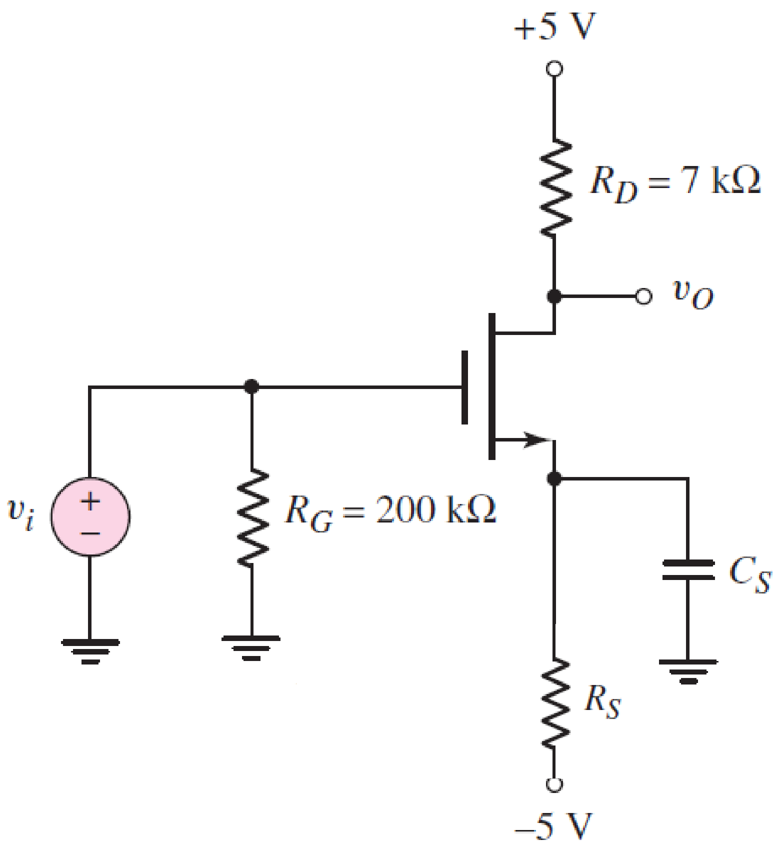
Bypass capacitor: It minimizes the loss in the gain due to the resistor on the source

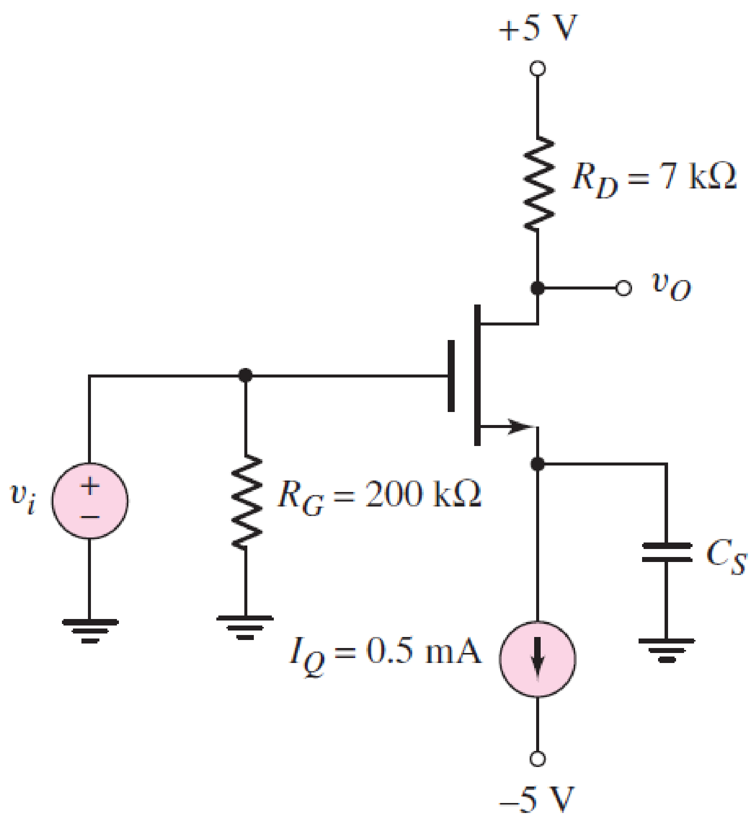


Determines transistor bias.

Note: the internal resistance of a real current source would affect the Q point just as R_s in the circuit on the lhs.

Review: Common Source (CS) Amplifier





High

$$R_i = R_G$$

Moderate

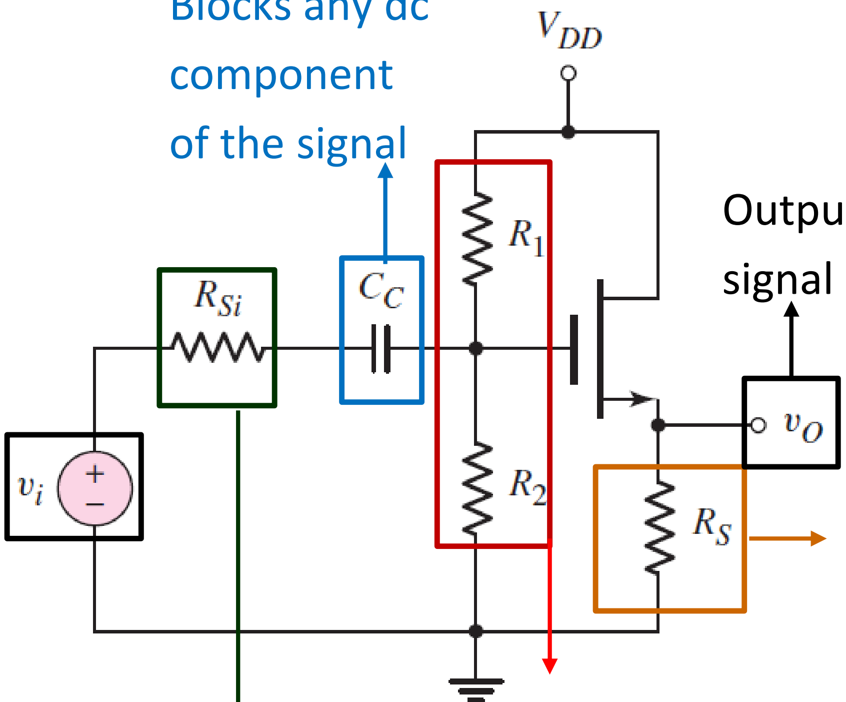
$$R_o \approx R_D$$

High

$$A_{vo} \approx -g_m R_D$$

Common drain (CD) FET amplifier

Blocks any dc component of the signal



Output signal

Input signal

R_S determines the Q point and acts as an internal load in ac.

Note: The load can also be the input resistance of the next amplification stage in a multi-stage amplifier.

Determine transistor bias along with V_{DD} and R_s

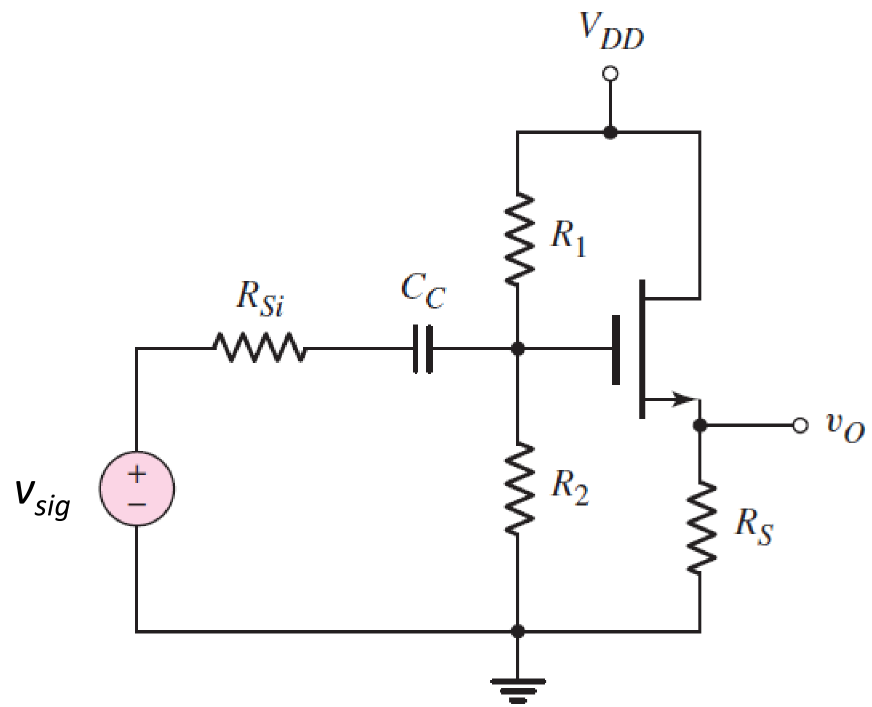
Internal resistance of a signal source or Thevenin equivalent of the output circuit of another amplifier stage.

C_{c1} ~10s μF. This value guarantees a much smaller capacitor impedance than R_{si} for signal with frequencies higher than 2 kHz. It can be treated as a short-circuit in ac at those frequencies

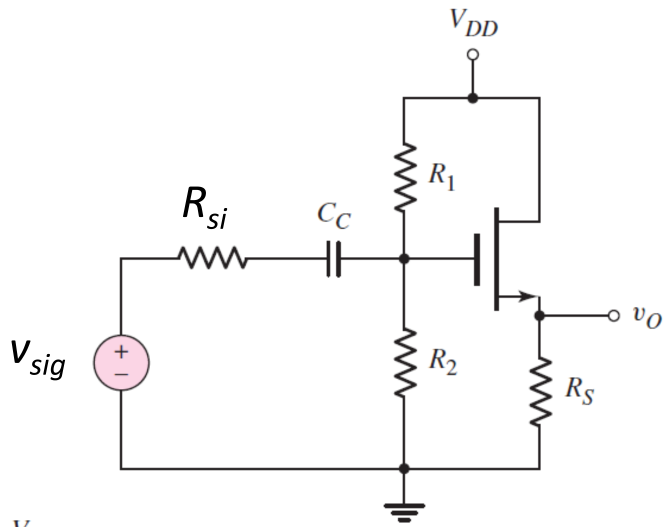
In class problem 1

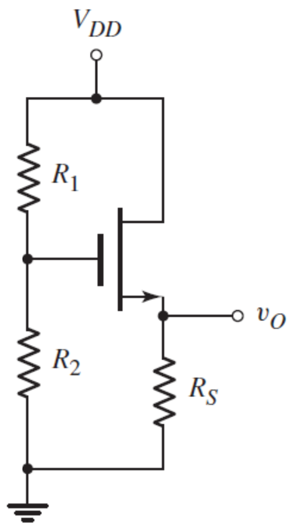
Sketch the AC and the small-signal equivalent circuit of the common drain amplifier below. Determine the expressions for the input and output resistance, the open circuit voltage gain, the amplifier gain and the overall voltage gain. Consider $\lambda \neq 0$.

Assume a mid-band frequency for the input signal.

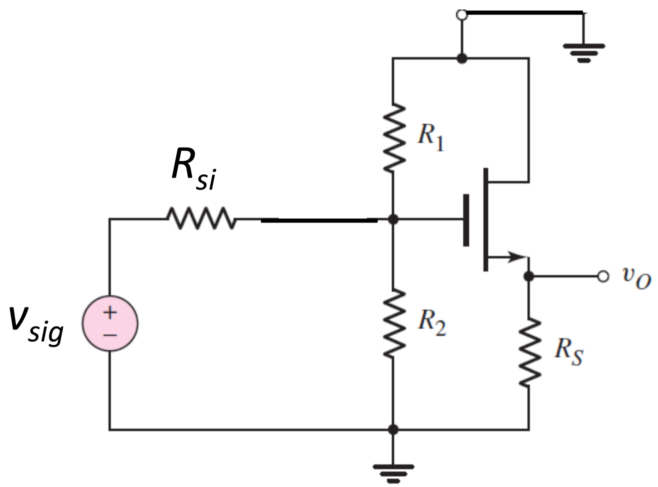


In class problem 1-Solution



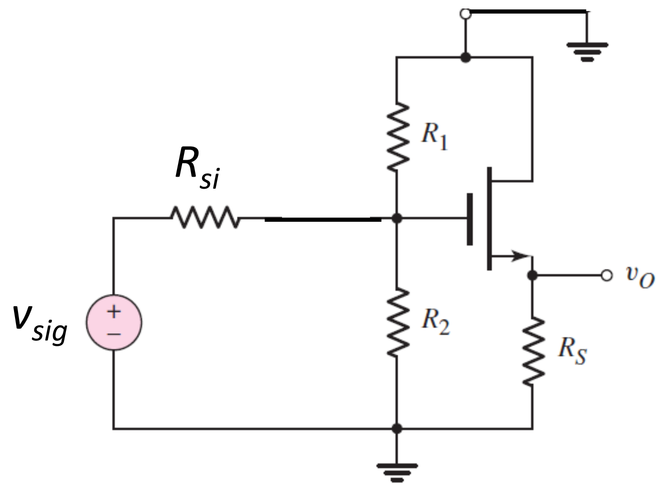


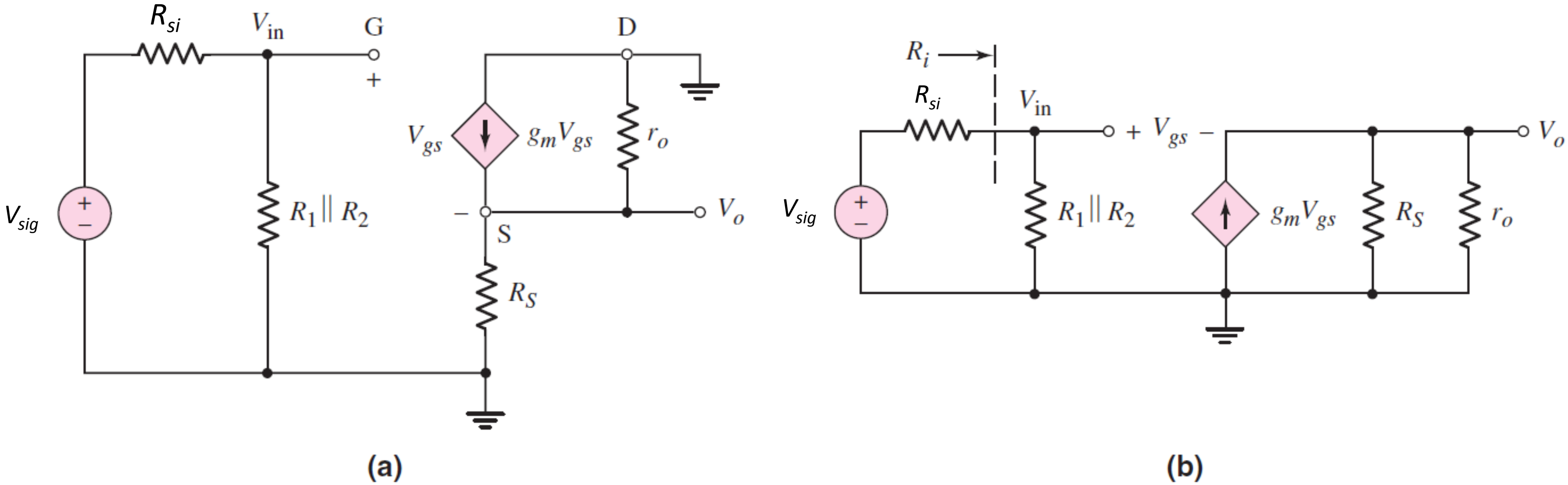
DC circuit



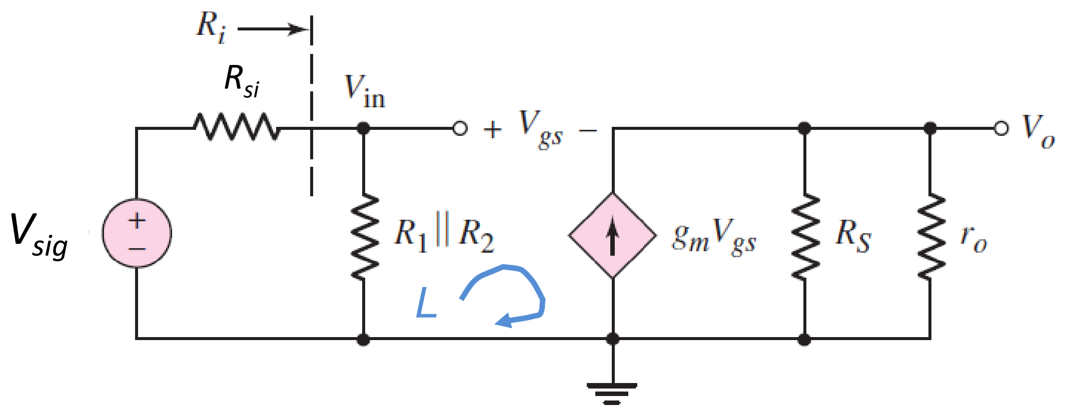
AC circuit

In class problem 1-Solution





In class problem 1-Solution



Input resistance

$$R_i = R_1 \| R_2$$

Gain

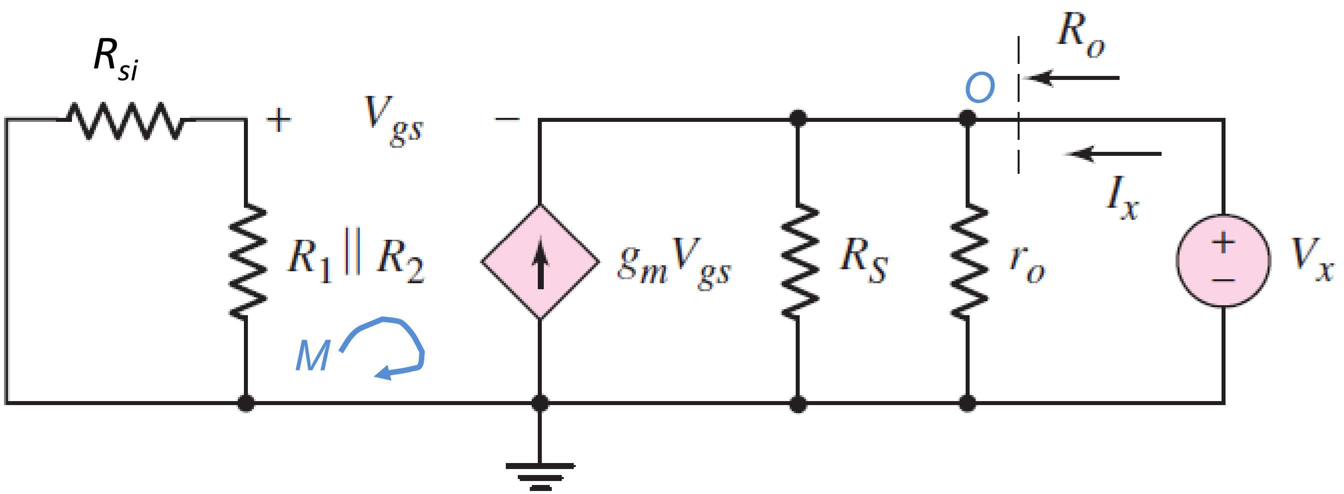
KVL @ L

$$V_o = (g_m V_{gs})(R_S \| r_o) \qquad V_{in} = V_{gs} + V_o = V_{gs} + g_m V_{gs}(R_S \| r_o)$$

$$V_{gs} = \frac{V_{in}}{1 + g_m(R_S \| r_o)} = \left[\frac{\frac{1}{g_m}}{\frac{1}{g_m} + (R_S \| r_o)}\right] \cdot V_{in} \qquad A_v = \frac{V_o}{V_{in}} = \frac{g_m(R_S \| r_o)}{1 + g_m(R_S \| r_o)}$$

$$G_v = \frac{V_o}{V_{sig}} = \frac{g_m(R_S \| r_o)}{1 + g_m(R_S \| r_o)} \cdot \left(\frac{R_i}{R_i + R_{Si}}\right) = \frac{R_S \| r_o}{\frac{1}{g_m} + R_S \| r_o} \cdot \left(\frac{R_i}{R_i + R_{Si}}\right)$$

In class problem 1-Solution



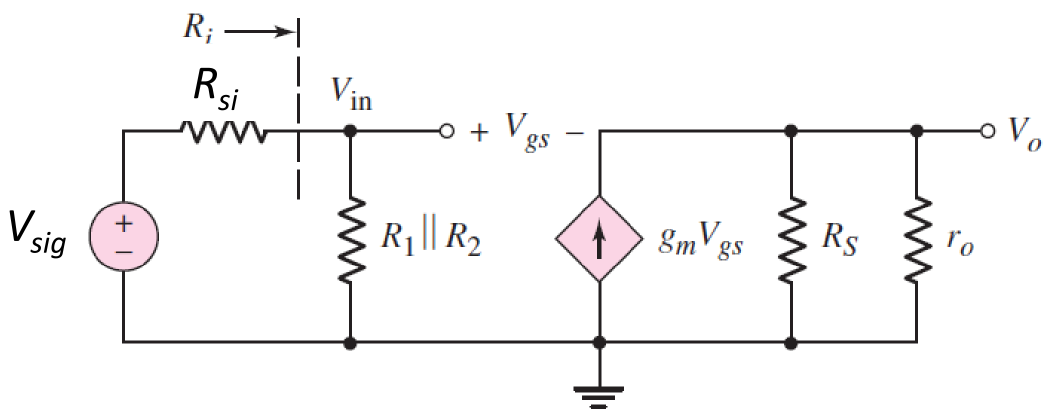
KCL @ O

KVL @ M

$$R_o = \frac{V_x}{I_x} \qquad I_x + g_m V_{gs} = \frac{V_x}{R_S} + \frac{V_x}{r_o} \qquad V_{gs} = -V_x \qquad I_x = V_x\left(g_m + \frac{1}{R_S} + \frac{1}{r_o}\right)$$

$$\frac{I_x}{V_x} = \frac{1}{R_o} = g_m + \frac{1}{R_S} + \frac{1}{r_o} \qquad R_o = \frac{1}{g_m} \| R_S \| r_o$$

In class problem 1-Solution



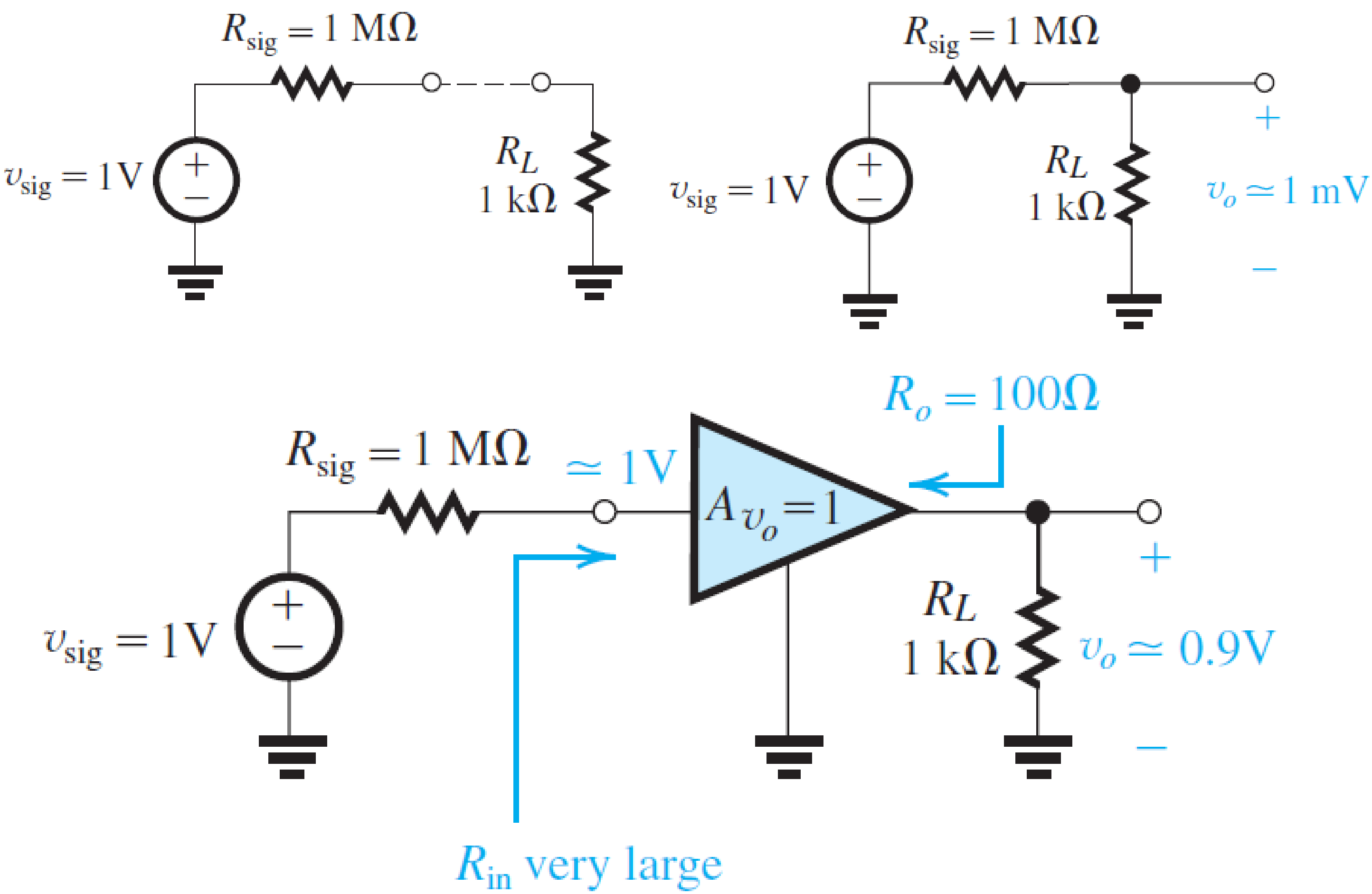
$$R_i = R_1 \| R_2$$ ***High***

$$G_v = \frac{R_S \| r_o}{\frac{1}{g_m} + R_S \| r_o} \cdot \left(\frac{R_i}{R_i + R_{Si}} \right)$$ ***Positive and ≤1***

$$R_o = \frac{1}{g_m} \| R_S \| r_o$$ ***Low (Dominated by 1/g_m)***

Because the output signal is in phase with input signal and it has close amplitude to it, this circuit is also called the source follower.

Application of the source follower: Voltage buffer



A source follower can be used to transfer a high amplitude voltage from a source with a large internal resistance to a load .

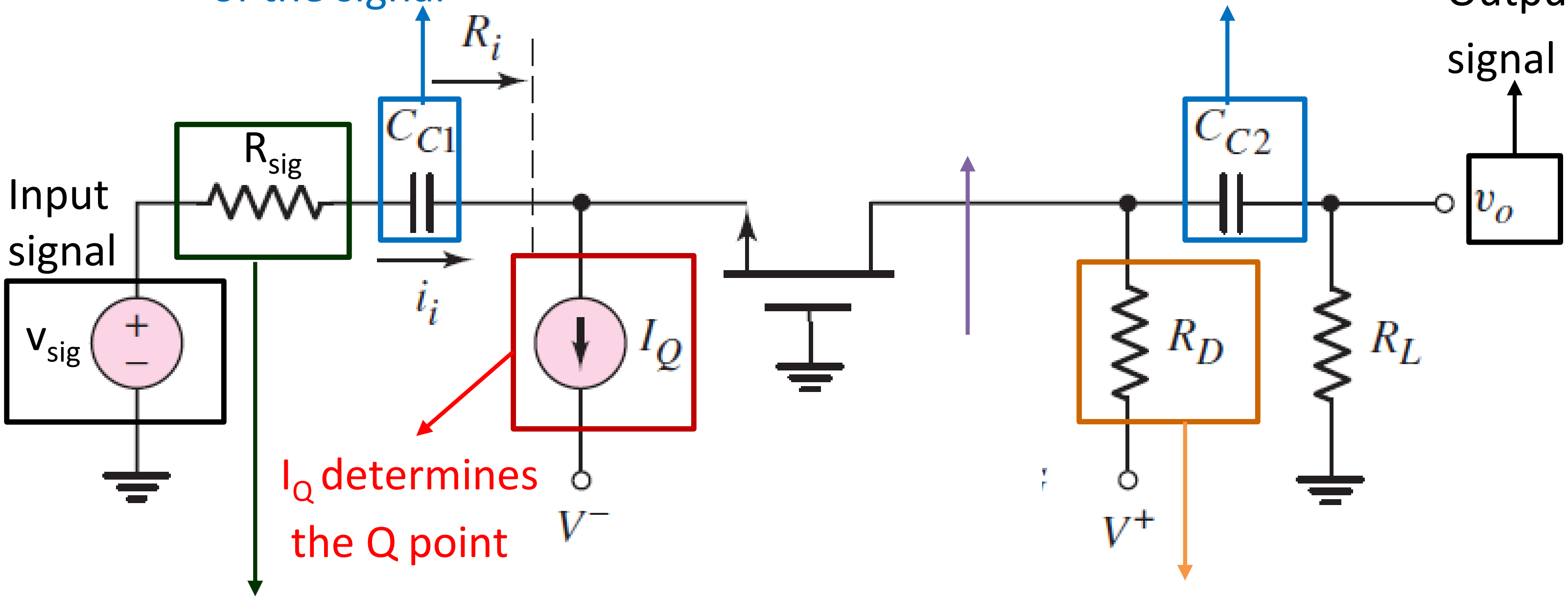
Common Gate (CG) FET amplifier

Blocks any dc component of the signal

Blocks any dc component of the signal

Output signal

Input signal



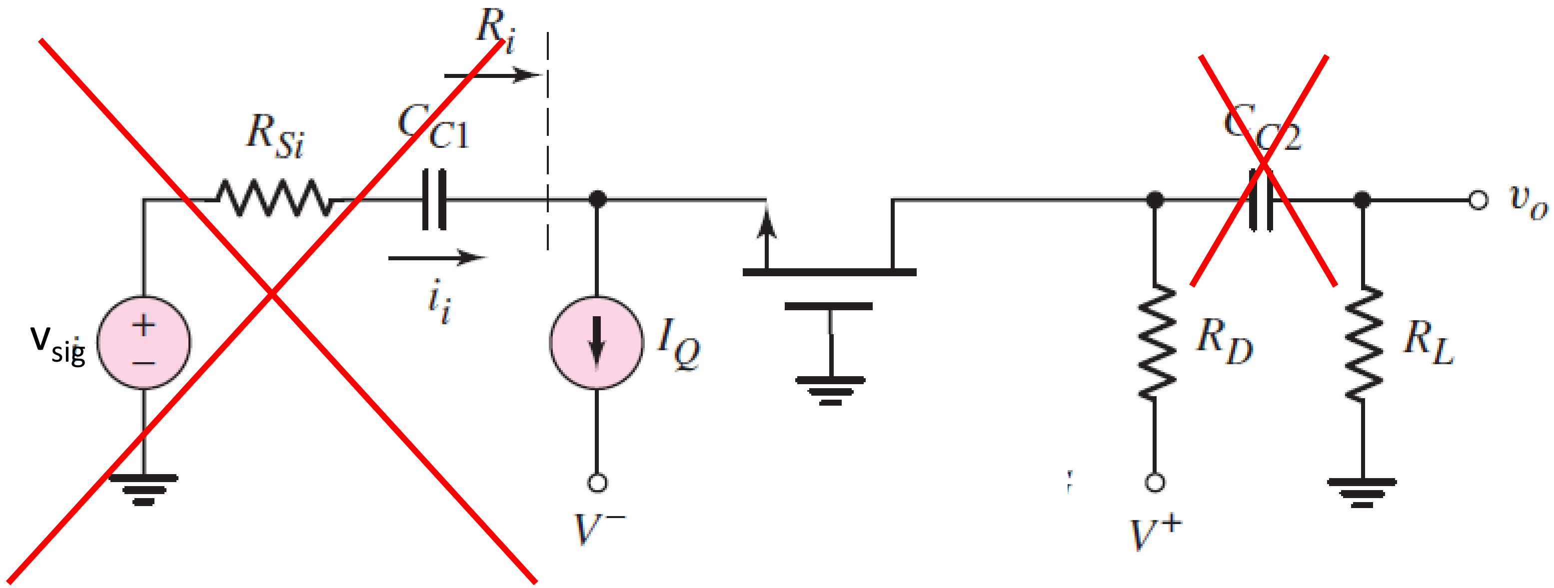
I_Q determines the Q point

Internal resistance of a signal source or Thevenin equivalent of the output circuit of another amplifier stage.

R_D determines the Q point along with I_Q, V^+, and V^-. It also acts as an internal load in ac.

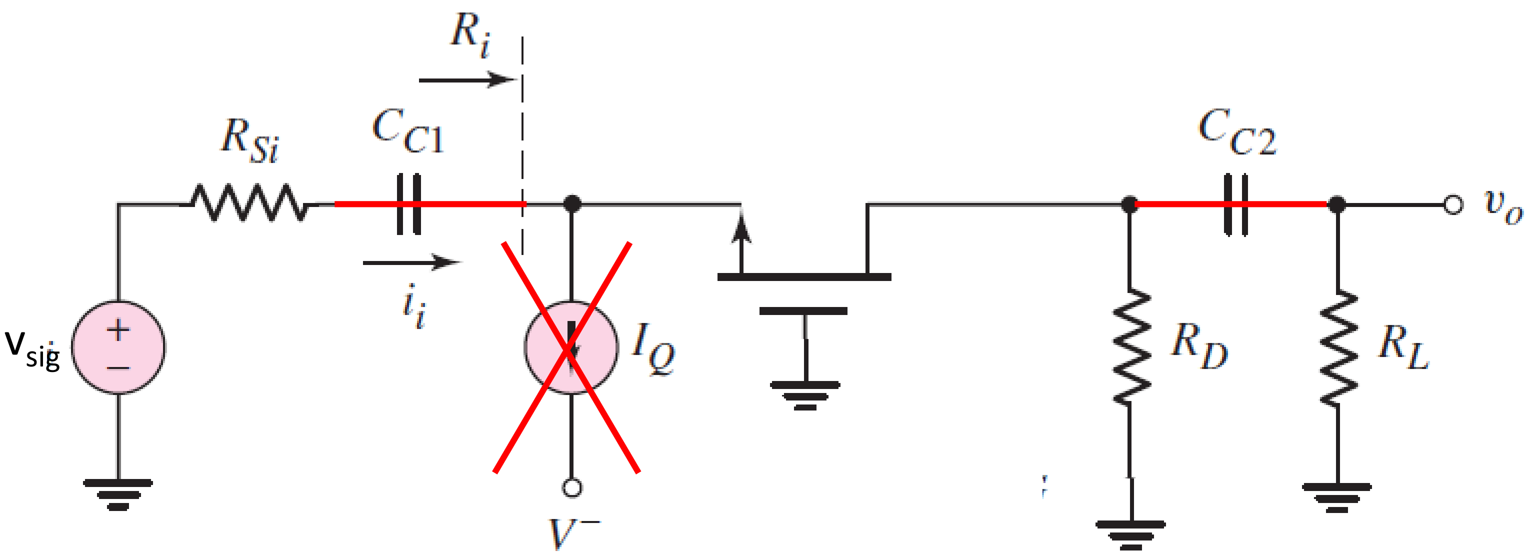
Common Gate (CG) FET amplifier

DC circuit



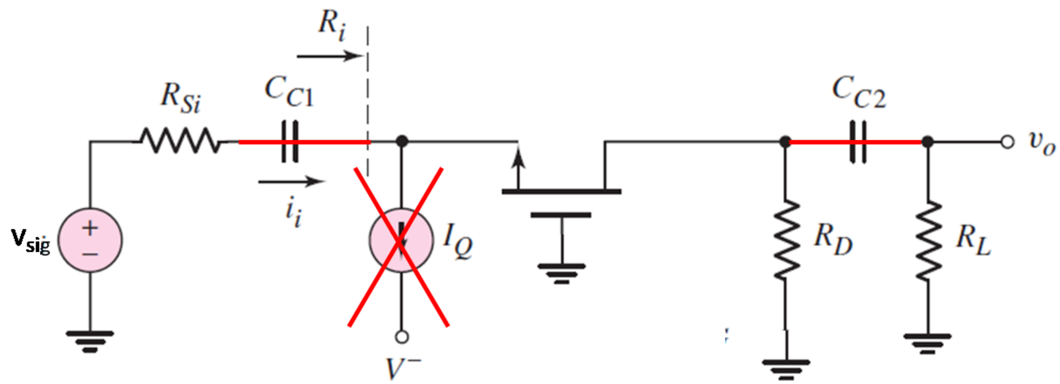
Common Gate (CG) FET amplifier

AC circuit

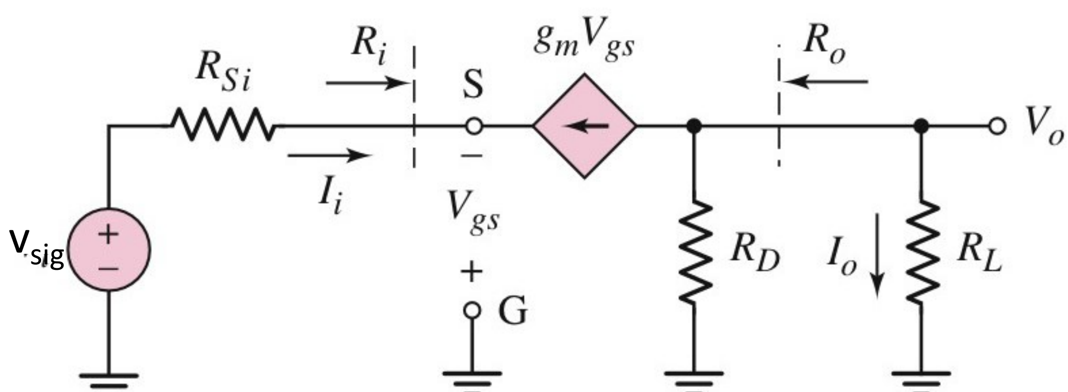


Common Gate (CG) FET amplifier

From AC to a small-signal equivalent circuit

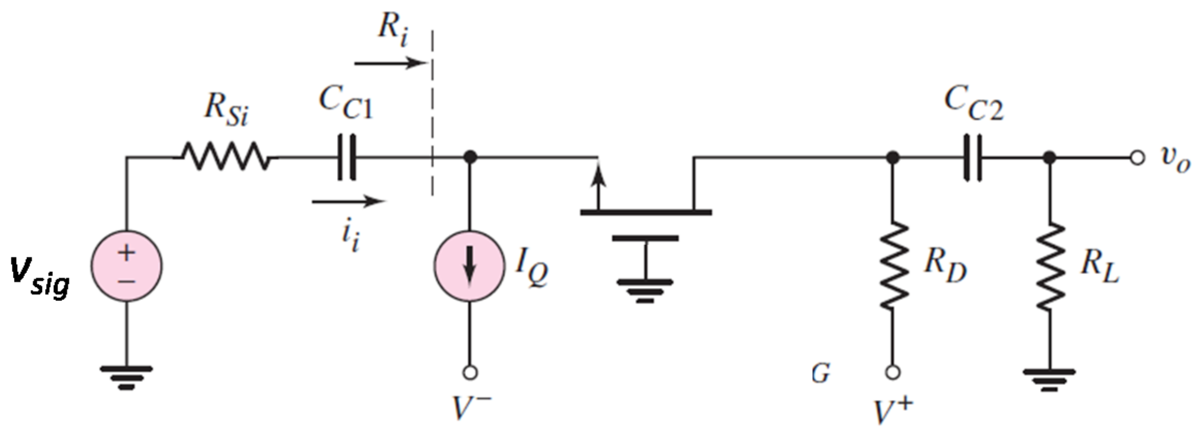


AC circuit



Small-signal circuit

Common Gate (CG) FET amplifier



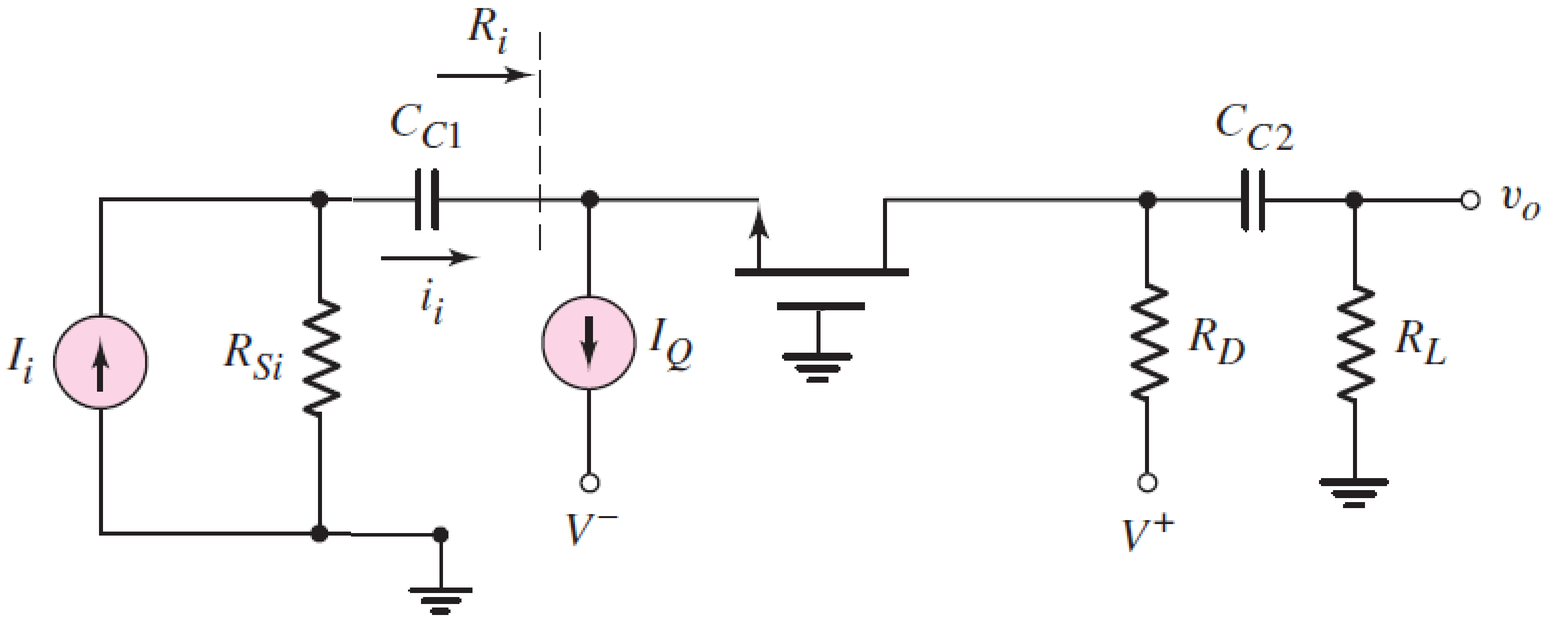
Input resistance* $R_i = \dfrac{1}{g_m}$ ***Low***

Overall gain* $G_v = \dfrac{g_m(R_D \| R_L)}{1 + g_m R_{Si}}$ ***Positive and large***

Output resistance* $R_o = R_D$ ***Low/Moderate***

- ***Practice calculating the performance parameters above and compare your approach to what is reported in the handout within the lecture 7 folder.***

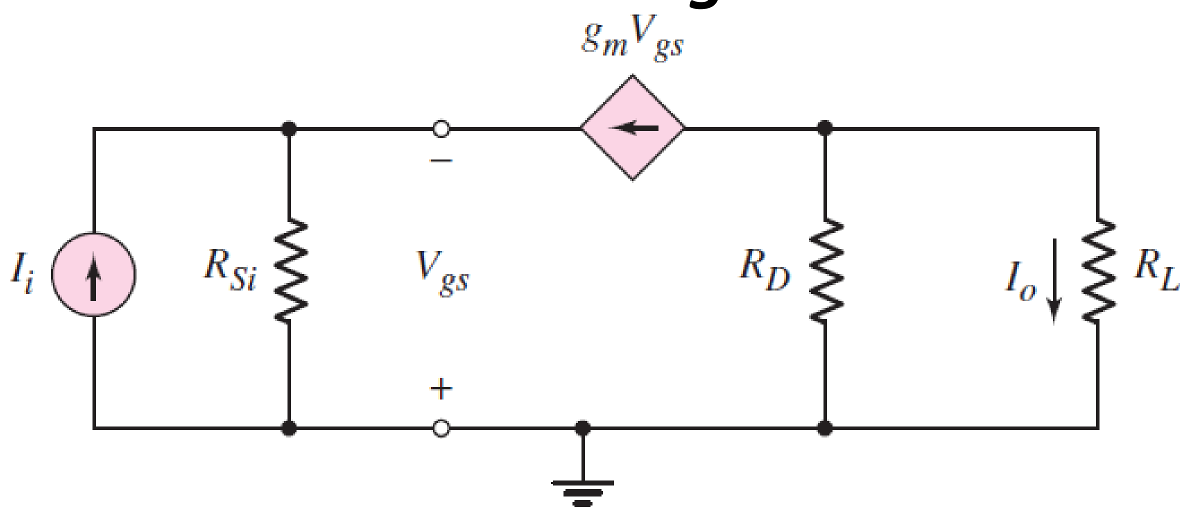
Common Gate (CG) FET amplifier as current amplifier



Common Gate (CG) FET amplifier as current buffer

Current gain

$$A_i = \frac{I_o}{I_i}$$



$$I_o = \left(\frac{R_D}{R_D + R_L}\right)(-g_m V_{gs})$$

$$I_i + g_m V_{gs} + \frac{V_{gs}}{R_{Si}} = 0$$

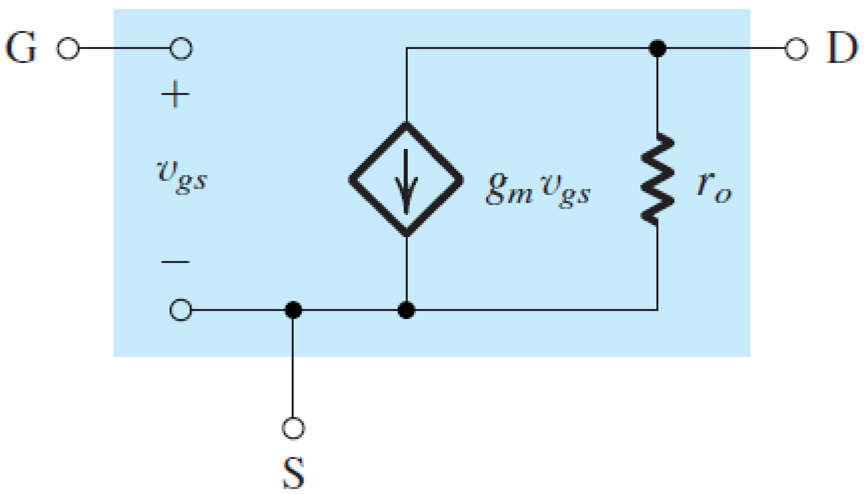
$$V_{gs} = -I_i\left(\frac{R_{Si}}{1 + g_m R_{Si}}\right)$$

$$A_i = \frac{I_o}{I_i} = \left(\frac{R_D}{R_D + R_L}\right) \cdot \left(\frac{g_m R_{Si}}{1 + g_m R_{Si}}\right)$$

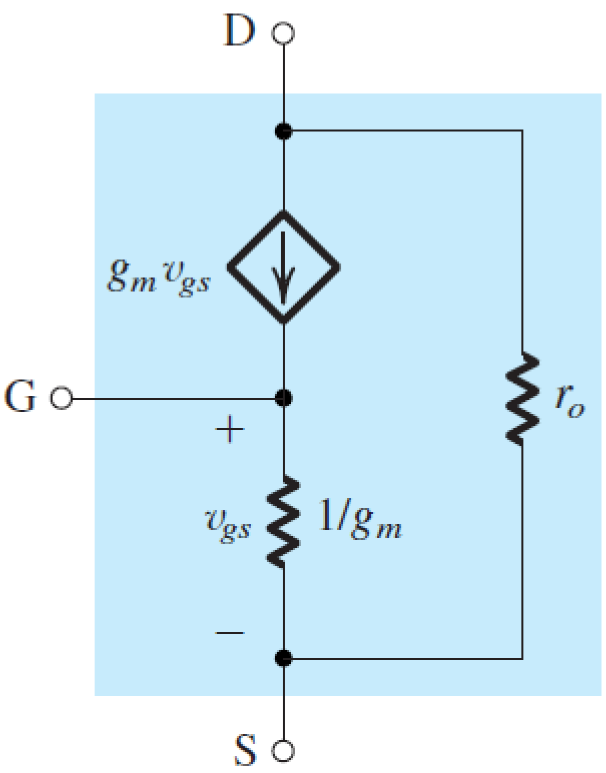
If R_D>>R_L the current gain is close to 1 as $g_m R_{si}$>>1
Application: current buffer between high current sources with low internal resistance and high loads

Small-signal equivalent circuits

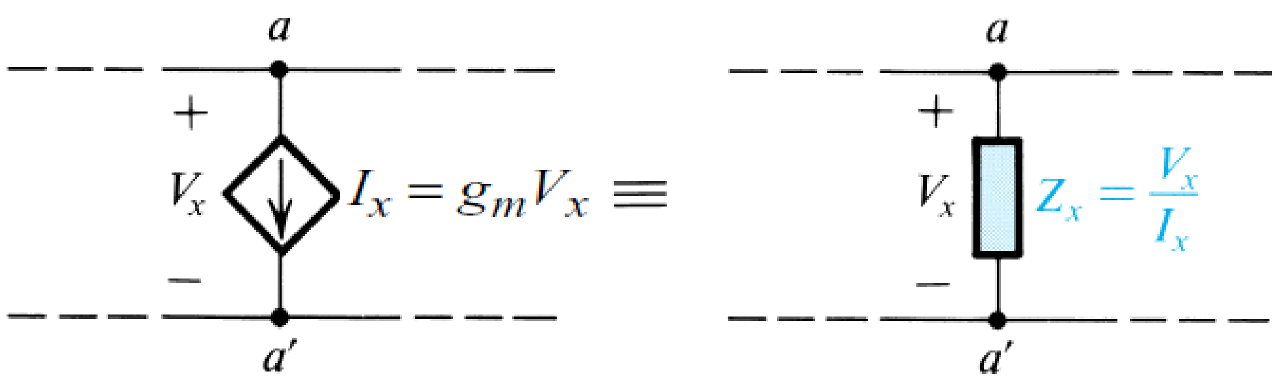
Π model



T model



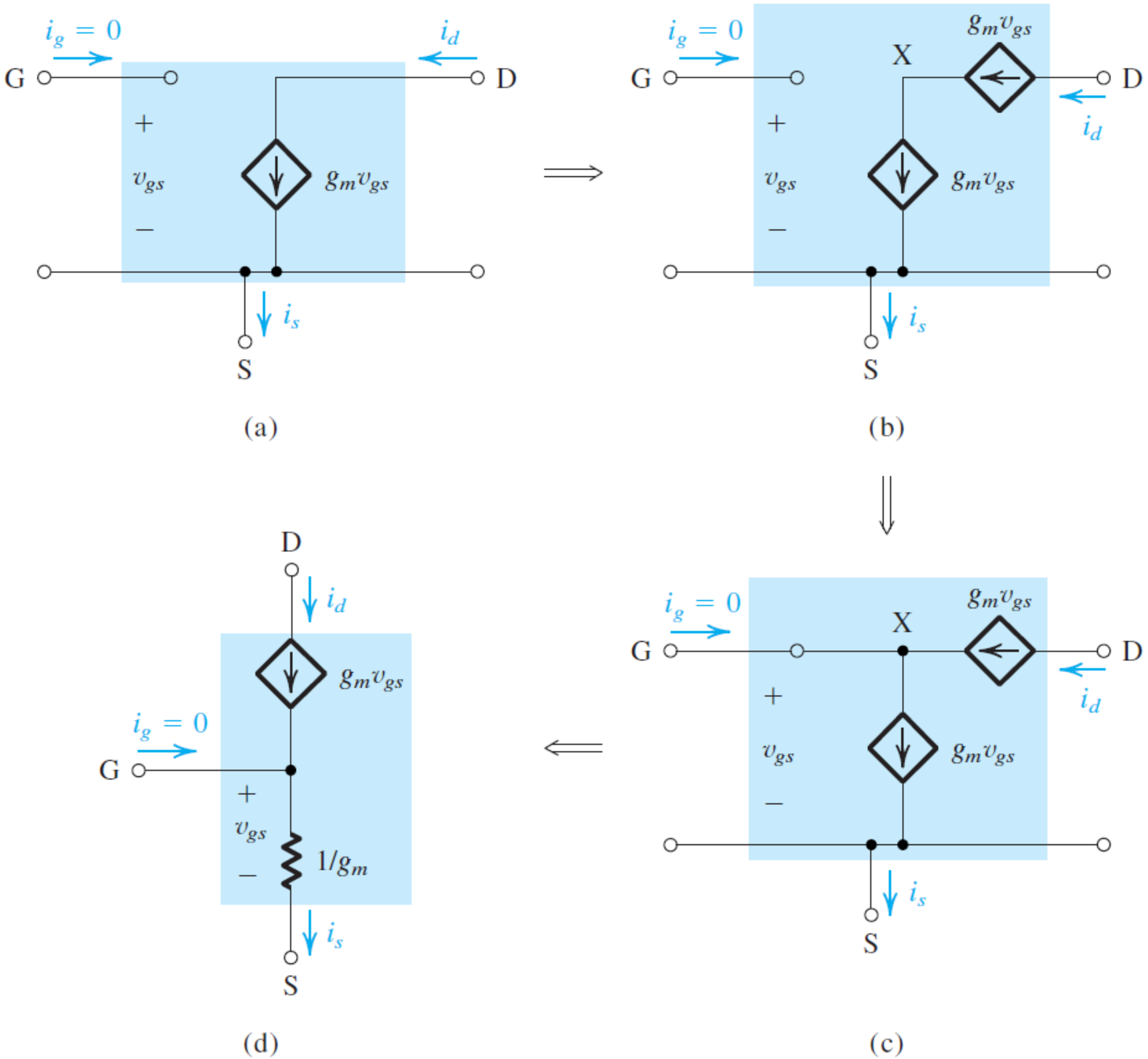
Source-absorption theorem



The current **source-absorption theorem** establishes that if, in one branch of the circuit with a voltage Vx, there is a dependent current **source** controlled by Vx, the **source** can be replaced by a simple impedance with value equal to the 1/**source controlling factor**.

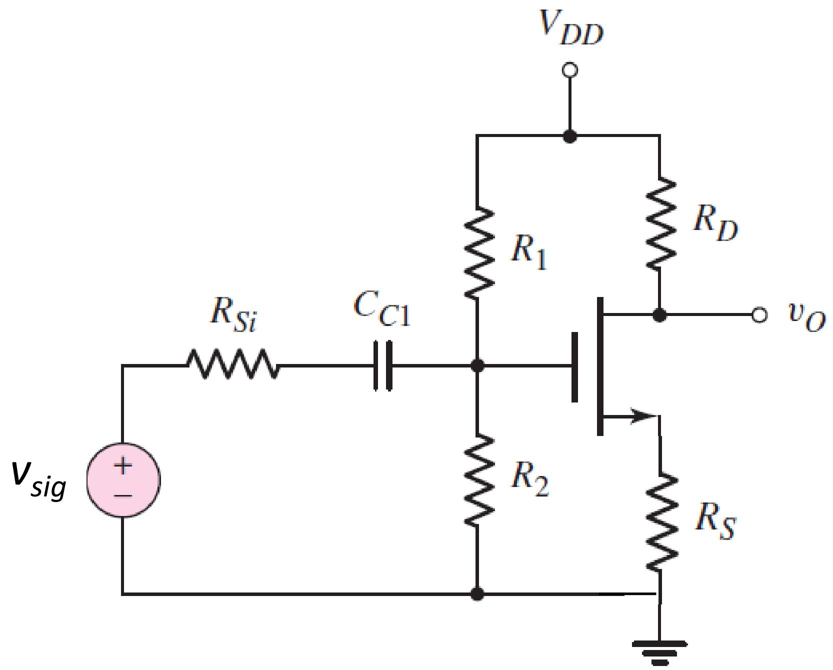
(S&S Appendix D)

Conversion from a Π to a T model



Take-home problem

Sketch the small-signal equivalent circuit of the common source amplifier below. Determine the expressions for the input and output resistance, the open circuit voltage gain, the amplifier gain and the overall voltage gain. Use a T model. Consider two cases: λ=0 and $\lambda \neq 0$.



Overview of lecture 8

- Comparison of the three basic amplifier configurations (Neamen 4.6, S&S 5.6.7)
- Single-stage IC MOSFET amplifiers

  Amplifiers with enhancement load

  (Neamen 4.7.1-4.7.2)